Case Study – Vibration

To investigate the effect of building vibration and its contribution, if any, to building structural and more importantly to the occupants' operation. To investigate if building vibration affects occupants operation, to what extend, and to advice on the counter measures that can be offered to counter vibration issues.

Abstract

A high-tech industrial building in Jurong, Building "C", is singled out by a prospective client as a suitable location for it new set-up for manufacturing in Singapore. The client, company "R", is a US based company manufacturing precision machinery parts whom has appointed local consultants to help them in it assessment of a suitable site for its manufacturing plant. The consultants are engaged to look into all aspect of the suitability of the "prospective building" in terms of structural, facilities and ancillary support requirements.

This report attempts to investigate and highlight the issues of vibration which building owners and building occupiers are concern with. In order to fully understand vibrations, the issue of noise will need to be looked into as there exists a relation between these two.

Introduction

Vibration issues are often linked to noise issue as there exists a relation in between them. Noise nuisance often translate to vibration issue. Thus in order to fully understand the issue of vibration, the noise issue will also be highlighted and study in this report.

Objective

Floor vibration is an issue that is slowly becoming an area of concern to building owners, this is especially so for building owners of industrial and high tech buildings which lease out their floor space to manufacturing companies and companies with operating which are sensitive to vibrations. The goal of this report is to investigate and highlight areas of concern, for building owners and buildings occupiers, issues relating to vibration and noise in the buildings. A case study for the testing of floor vibration is used in this report to facilitate this study.

The report has three primary objectives:

1. to highlight the concerns of vibration and noise effects on buildings, from both the owner and occupiers perspective;

2. to explore good practices that can be adopted to contain vibration issue for the on set of the construction of the building;

3. to recommend effective ways of controls to counter the effect of vibration.

As Noise and vibration problems are correlated to one another, the control of noise problem affecting vibration issues will also be highlighted in brief.

Literature Review

Introduction

Vibrations caused by human activity have long been recognized as a major serviceability concern for residential floor systems.

In Singapore, floor vibration serviceability issue is currently not addressed in floor system design, except for a limitation on working load to suit to the structural design of the building.

The Ministry of Manpower (MOM) legislation on The Factories Act (Chapter 104), which relates to the health, safety and welfare of persons employed in factories and other workplaces, however, mentioned, in relation to vibration issues, the health requirements of the Factories Act. Under Section 3 of the Special Health, Safety and Welfare Provisions (Part VII);

> Reduction of Noise or Vibration (64)
>
> Where in any factory persons are employed in any process or work involving exposure to excessive noise or vibration which may constitute a danger to their health, effective means shall as far as practicable be provided for the reduction of the noise or vibration.

The above Clause meant that an employer has a duty of care to ensure that their employees are protected fro undue noise or vibration nuisance resulting for its operation.

As spelled out in other guidelines, i.e. The Occupational Safety and Health Guidelines, noise and vibration hazards are a common feature which employee faced in their workplace.

Besides protecting employees from the harmful effect of noise and vibration to health, companies' next most important concern is the harmful effect of vibration on the products of its operation.

Noise and Vibration

Noise and vibration is one of the prevalent health hazards in the industry. Exposure to excessive noise can cause noise-induced deafness or hearing loss – a disease that may take several years to develop and cannot be cured.

Excessive noise and vibrations can seriously diminish the quality of life in neighborhoods and communities. Where violations occur, strategies for limiting noise emissions must be undertaken.

Environmental sound and vibration can originate either from inside structures or from a variety of outside sources such as transformers, vehicles, cooling towers, fans, motor-driven equipment, and a host of industrial machinery and processes. In addition to disturbing people, sound and vibration also can adversely impact certain types of processing equipment. For example, while humans can detect floor vibration exceeding a Root Mean Square (RMS) velocity of approximately 125 microns per second, certain equipment exhibits vibration-related malfunction if the floor vibration exceeds 6.25 microns per second. Moreover, noise transmission is affected by three major environmental influences: distance, atmospheric conditions, and terrain/vegetation. When existing environmental sound and vibration adversely influence the success of a project, it may be necessary to perform an Environmental Sound and Vibration studies to evaluate the impact of these factors prior to construction. A complete Environmental Sound and Vibration Study contains three elements;

- Sound and Vibration Study,
    - A study of where sound and vibration originates. This study assesses the possible noise and vibration emitted for plants and machineries.

- Ambient Noise Study and
    - This study established the ambient noise permissible for a proposed project or case study.

- Noise Prediction Study.
    - This study predicts the noise and vibration that may be contributed to the subject area due to the surroundings and its environment.

However, depending on the requirement of building owners, not all 3 studies are necessary. When a comprehensive study is not required, performing any of the 3 elements of a complete Environmental Sound and Vibration Study can be done individually.

With the establishment of the noise and vibration study made on plants and machineries, the ambient noise levels for a proposed project can measured and assessed. By using the existing noise levels, comparing them with applicable land use restrictions and permissible local noise regulations. One may predicts how ambient conditions will affect the proposed project. By predicting the surrounding environment's emission and contribution of noise and vibration, methods for reducing noise levels can be recommended to ensure compliance to permissible levels as provided by local legislation.

Equipment noise is either measured or estimated, based on known sources for a specific type of equipment. Sound levels from environmental sources, such as outdoor equipment and traffic can be measured, i.e. Traffic noise calculations account for traffic flow patterns, speed limits, terrain, distance from the road, and the car/truck ratio.

Worldwide demand for faster, smaller and higher-capacity electronic products continues to fuel the development and expansion of high-tech buildings. The very stringent requirement of sensitive instruments and complex manufacturing processes often necessitates that building to cater to the need for specific floor vibration specification. This has made the micro-vibration study an essential part of the structural design of these buildings and a challenging task to accomplish due to increased activities in today's environment. In this context, this transform to the need to understand several critical issues pertaining to the conceptual design of high-tech building as well as the vibration-sensitive floor system to meet these demands.

With the advancements in materials and technology, longer spanning and lighter weight floor systems are now available. Such floor systems may be designed for only strength and may be susceptible to excessive floor vibrations due to human footfalls. The easiest and most economical way to avoid a problem floor is to limit this possibility in the design stage of the floor system.

Fundamentals of Sound and Vibration

Sound is generated by vibration of surface or by turbulent fluid flow, which sets the air molecules into motion. It is a wave motion due to air pressure variations. Sound can propagate in gases, liquid and solids, but it cannot propagate in vacuum.

The frequency of sound wave is the rate at which the air pressure variations occur. Frequency is perceived as the pitch of a sound and is expressed in cycles per seconds (c/s) or Hertz (Hz). Sound pressures refer to the root mean square value of the pressure changes over and below the atmospheric pressure and are expressed by dBA.

The permissible exposure limits for noise are stipulated in the Factories (Noise) Regulations. No person shall be exposed to an equivalent sound pressure level of 85dBA over an 8-hour work day.

Table 3 Permissible noise exposure limits

Sound Pressure Level (SPL), dBA	Maximum Duration (T) per Day	
82	16 hrs	
83	12 hrs	42 mins
84	10 hrs	5 mins
85	8 hrs	
86	6 hrs	21mins
87	5 hrs	2 mins
88	4 hrs	
89	3 hrs	11mins
90	2 hrs	31mins
91	2 hrs	
92	1 hr	35 mins
93	1 hr	16 mins
94	1 hr	
95		48 mins
96		38 mins
97		30 mins
98		24 mins
99		19 mins
100		15 mins
101		12 mins
102		9 mins
103		7.5 mins
104		6 mins
105		5 mins
106		5 mins
107		3 mins
108		2.5 mins
109		2 mins
110		1.5 mins
111		1 min

Source : MOM

Noise is unwanted sound but the two terms, noise and sound, are often used interchangeably.

When a noise source is placed on the outside environment, the sound wave will propagate from the source and there are no fixed boundaries to reflect these sound waves. However, in a room, the same sound wave will reflect from the boundaries of the room.

The noise level which a person may be subjected to in a room can come from 3 factors:

1. direct noise from machinery which is nearby,
2. reflected or reverberant noise from one or more machines emitted from a distance,
3. a combination of the above.

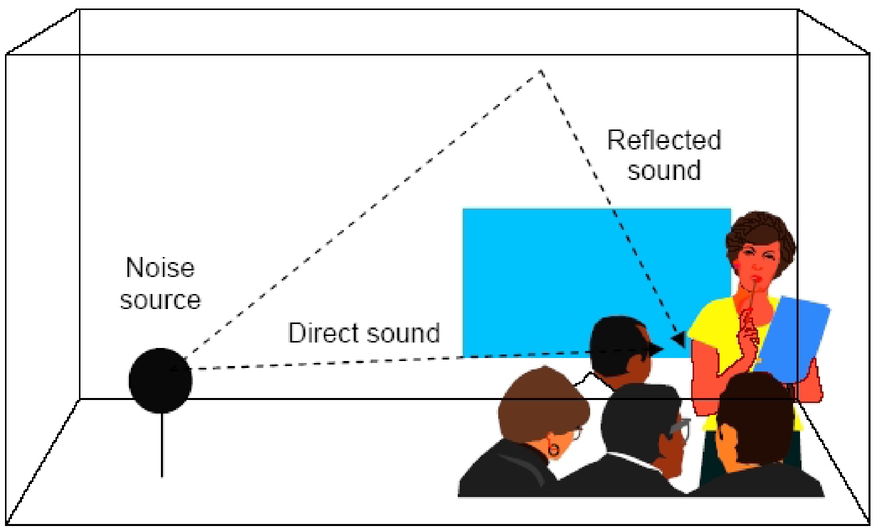


Fig 1 Propagation of noise in a room

Source : MOM

Vibration that occurs in buildings are often contributed by plants and machineries in the building itself. Mechanical vibration is an oscillatory motion about an equilibrium position produced by a disturbing force. Such vibration can produce structural damage, undesirable physiological effects and excessive levels of airborne noise. Periodic disturbing forces are produced mechanically by unbalanced, mis-aligned, loose or eccentric parts of rotating machinery which are also produced aerodynamically and hydraulically. Non periodic forces are produced by sliding or rolling parts, turbulent fluid and jet discharges.

Vibrations are transmitted from machines to the structural floors which machine sits on. From the structural floor, vibration is further transmitted and spreads to beams, columns and to the next floor. Basically, as a buildings' structural frame is made up of a framework of slab, beam and column, vibration is transmitted to each connected member and spreads on to each other connecting members.

Response of a floor system is the ensuing motion after an initial displacement. In layman's term, this means the motion that is pick up after something has pass the floor, say for example, the motion that is detected after a person walks pass the area of the test. Vibration test is represented as a time variation of displacement, velocity or acceleration. Dynamic loading is classified as either repetitive or transient loading where both repetitive and transient loading can occur from the movements of people, i.e. walking, jumping, and dancing.

Natural frequency is the frequency at which a structure will vibrate after sudden impact. Fundamental frequency technically refers to the lowest natural frequency present.

Damping is a measure of how quickly the amplitudes of a freely vibrating system decay. It is usually expressed as a ratio of present system damping to critical damping. Typically, most floor systems have damping much less than critical damping (1% to 5% of critical). Lightweight floors systems (timber or light gauged steel framed) tend to have more internal damping than concrete slab-steel beam floor systems.

Resonance will occur in a system if the system is being excited by a force that has a frequency equal to the natural frequency of the system. The result is very large amplitudes which must be avoided.

Case Study – Floor Vibration Test

Background

Company "R", a US based company dealing with manufacturing of precision machine parts has the intention to set up a manufacturing plant in Singapore.

Company "R" appointed local consultants to help them in finding a suitable location for its set-up of the plant. All aspect of the building performance, which is necessary to meet their basic needs was scrutinize and studied in depth by its consultant.

One of the sites which suited company's "R" needs was Building "C".

Building "C" – External

Company "R" on having made many a visit with its teams of consultant to make verification on the buildings performance picked Building "C" and single out level 5 for it production floor and level 6 for it office. A total floor area of 11,300 sqm.

Proposed 5th Level Production Floor

Overview of 5th Level Unit

Overview of 5th Level Unit

Overview of 5th Level Unit

The required floor loading for company “R” is 5 kN/sqm. The level singled out by them is 7.5 kN/sqm for level 5 and 5 kN/sqm for level 6.

Building “C” is a 7-storey high tech flatted industrial complex. It is specifically built with functionality in mind and offers the flexibility of modular floor layout and large expanses of virtually column-free floor space of 10 to 13 meters.

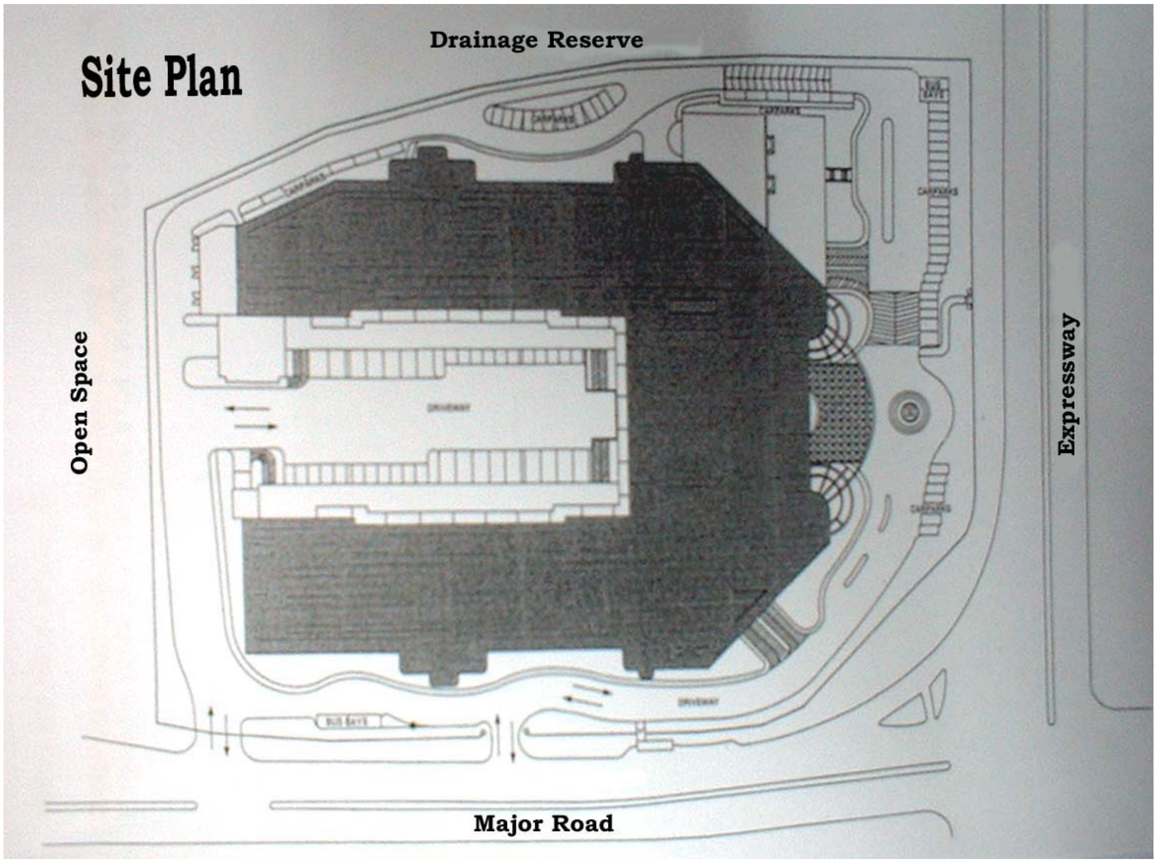
Building “C” – Southern Facing

Building “C” – Eastern Facing

Building “C” – Western Facing

Building “C” – Northern Facing

The layout of Building “C” suited company “R” requirements to house it assembly machine as it offers flexibility to design their operation needs. The main enticement for company “R” was in Building “C” outstanding location. The building is located close to the second linkway to Malaysia and Tanjong Pagar Ports and is within access to 2 major expressway; Alexandra Expressway (AYE) and Pan Island Expressway (PIE). Most importantly, the building provides excellent support for electrical power supply as it is supported by 4 PUB supply feeders of 22kV, which is a very much desired requirement set by the client’s demand for electrical support (See appendix for detail building information).



Site Plan of Building "C"

Building "C" – Southern Facing Expressway

Building "C" – Southern Facing Expressway

<u>Building "C" – Southern Facing Expressway</u>

<u>Building "C" – Eastern Facing Major Road</u>

Concerns of the Client

In terms of space needs and electrical support, Building "C" gave company "R" a very good reason for taking up the space for the set-up of its plant. However, other areas of concern were brought up by its team of Engineers, which may be a deciding factor for taking up the space in Building "C".

The concerns of the client are:

1. As the company is in the manufacturing of precision machine parts, the concern for vibration affecting its machines, and ultimately its end products, is a major concern. Building "C", as a high-tech building, houses several other companies in its premises. Therefore, it is necessary for company "R" to ascertain the current vibration, if any, that may be transmitted to its proposed production floor.

2. Although the location of the building is perfect for it the company's needs for connectivity to the transport network, it is highlighted by it Engineering team that there is a concern as vibration for the expressway may affect the quality of the company's end product.

3. The required floor loading for its machine is 5 kN/sqm which fitted comfortably for the 7.5 kN/sqm of the 5 level which the client has proposed to site the manufacturing plant. However, for its operation purpose, the required floor loading as required by its Engineers is to be a minimum of 9.5 kN/sqm.

4. For its manufacturing process, the client will need nitrogen gas as part of its process needs. Building "C" will need to cater to site a nitrogen tank for this purpose.

As it is of utmost importance that vibration is within an acceptable range as required by its Engineers, the consultant proposed for a floor vibration measurement to ascertain the suitability of the building.

As part of the consultant's evaluation, the client requested a study of the buildings vibration profile; the consultant suggested a profiling of vibration in the proposed production floor over a 24-hour period with the floor vibration measurement represented as a time variation of displacement, velocity and acceleration.

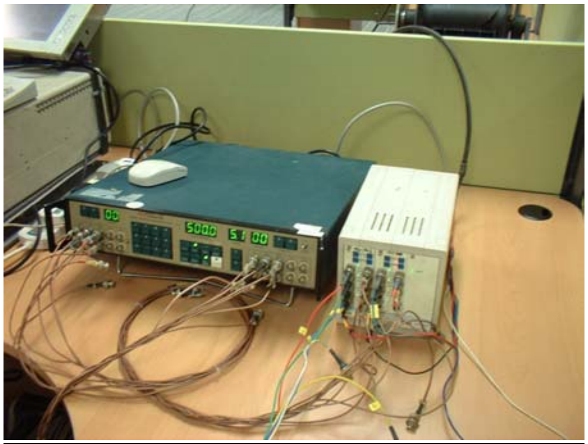
Floor Vibration Test

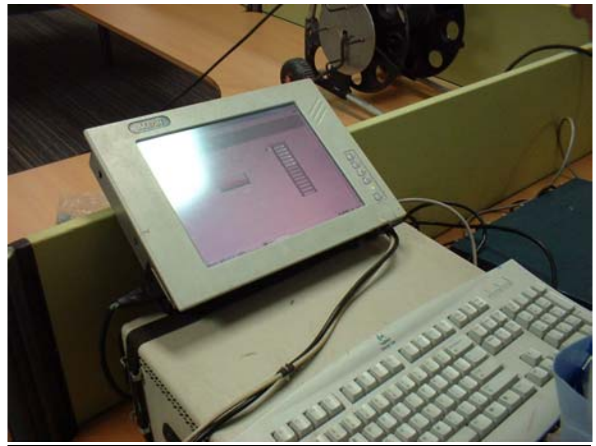
On the request of the client, the landlord proceeded to hire a 3rd party consultant to conduct the floor vibration measurement to the client's requirement.

The objective of the client is to monitor a 24-hour period of the building's vibration profile to facilitate its study on the suitability of the building to meet its operation needs. As the client was reluctant to deluge its specification for its machines, its local consultant was only required to collect all information necessary for its own Engineers to access the suitability of the building. Thus, the raw data for vibration profile of building was collected.

Two points on the proposed floor, 5th level, was monitored for the vibration profile in 3 directions, X-axis, Y-axis and Z-axis.

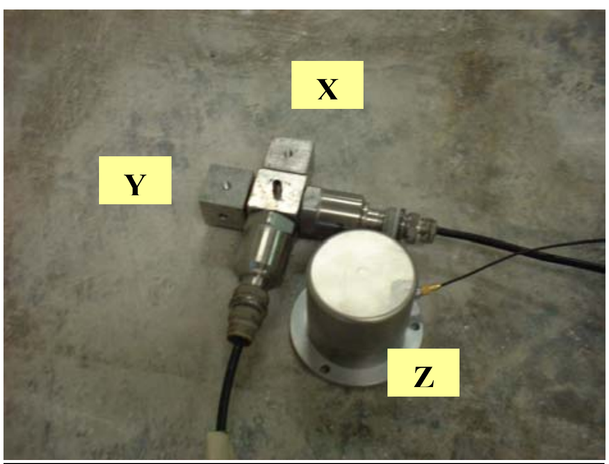
Data Acquisition Equipments

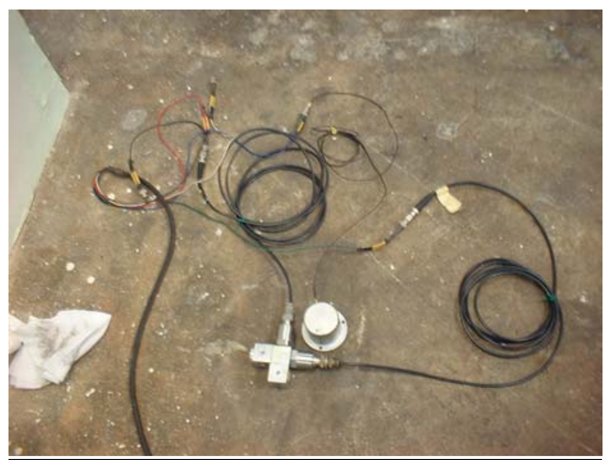




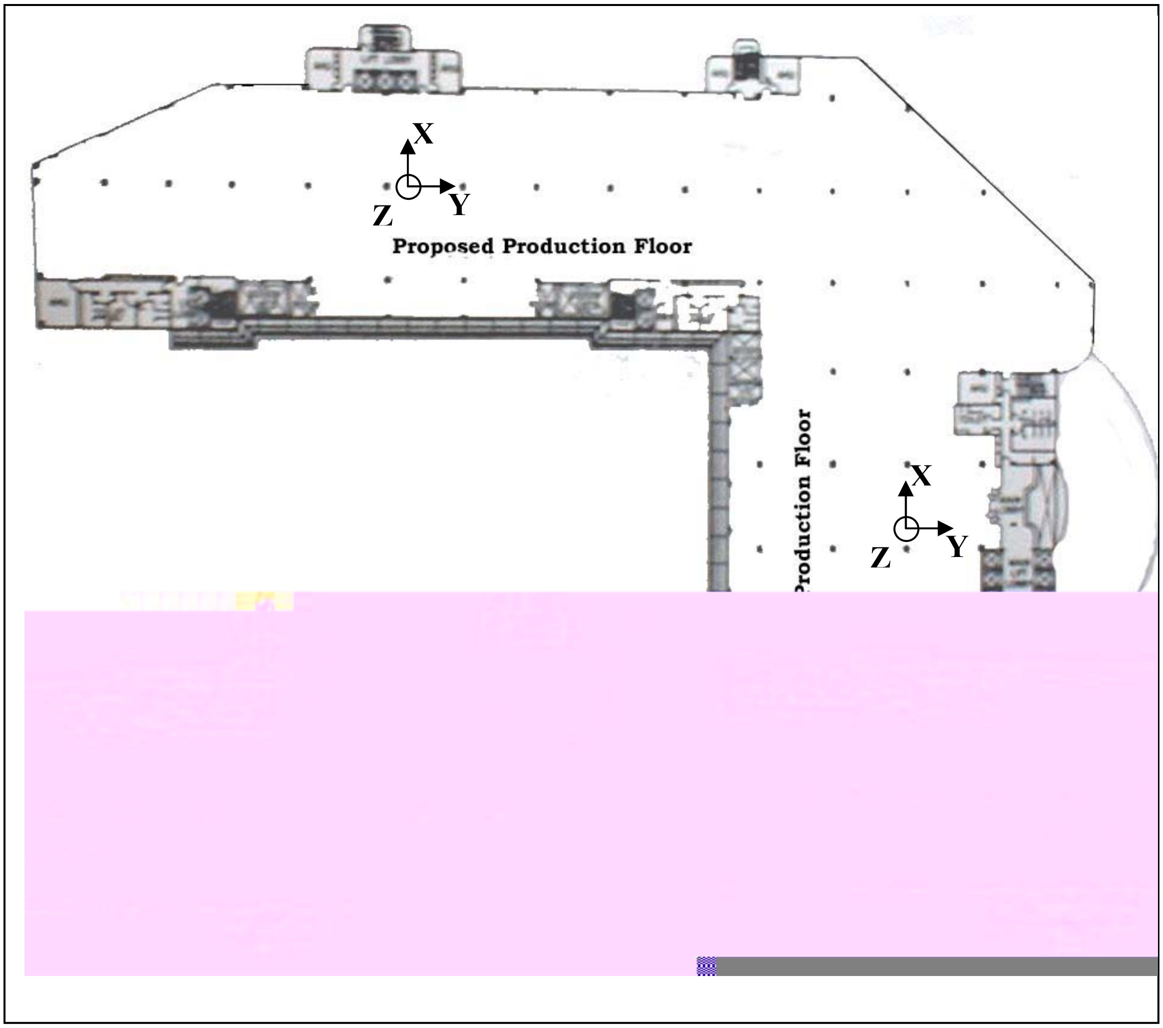
Amplifier & Front-end Filter **Data Acquisition System**

The floor vibration measurement was collected with a data acquisition system with a amplifier and front-end filter, fixed with accelerometer of 2.5g and 5g. Data was collected using a data acquisition setting sampling rate of 1300 Hz with a front-end analogue filter of low pass of 500Hz on 6 channels.





Accelerometers



Floor Plan showing the Location of the Accelerometer and the Axis for Data Collection.

During the period of measurement, vibration form the surrounding environment is captured. This includes the normal vibration from other tenant's operation and all other operation from the landlord, i.e. the change over of chillers, movement of cargo lifts, AHUs etc. A 24-hour profiling requested by the client was intended to capture all these external factors beside its primary concern on the vibration that may be contributed by the expressway.

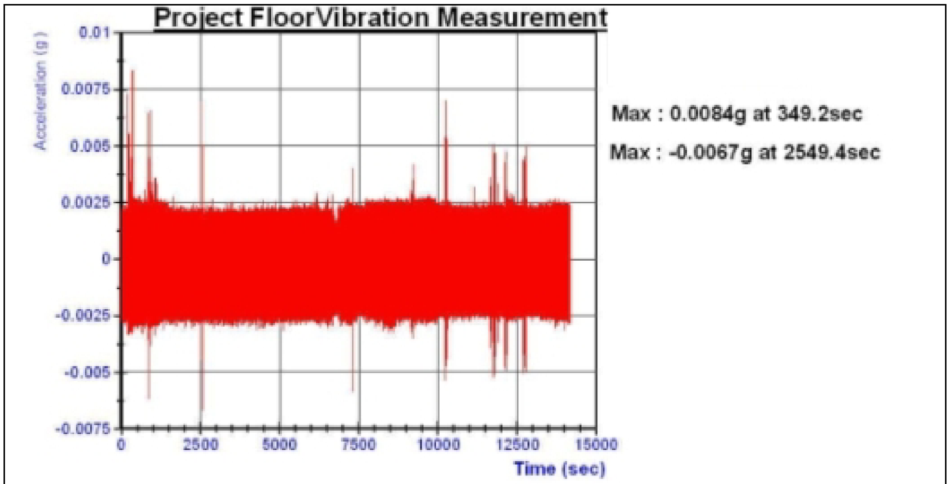
Measurement for the floor vibration was collected in 5 series over a 24-hour period. Each series represented a period of time between the 24 –hour period with 1 series measuring the vibration profile of the cargo lift in operation.

The Maximum Values collected over this period was tabulated as follows:

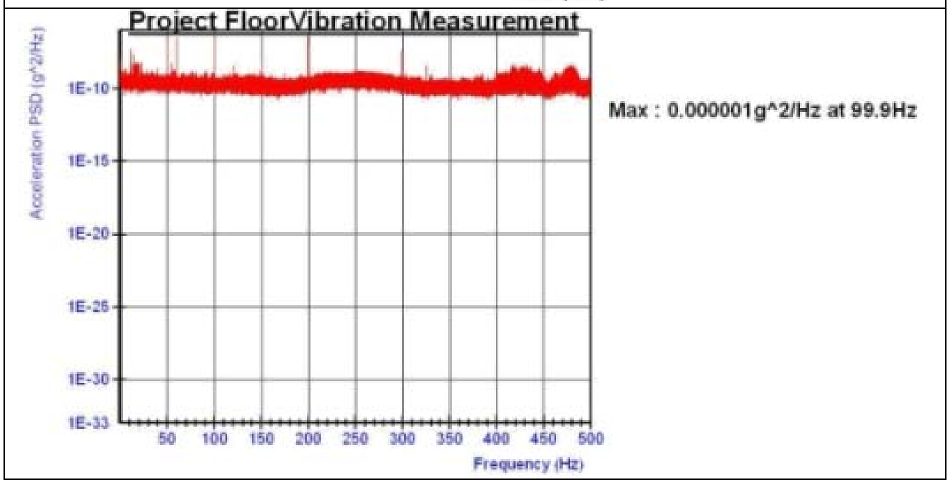
Location	PSD		FFT			Acceleration		Velocity		Displacement	
	Series	G^2/Hz	*Series*	mm/sec^2	*Freq.*	*Series*	*g*	*Series*	*mm/sec*	*Series*	*um*
Lot-1 – X	1	4.10E-06	4	0.21	24.66	2	0.011	2	1.4564	2	39.7
Lot-2 – X	1	1.60E-06	4	0.22	20.52	1	0.005	2	-0.4394	2	-12.8
Lot-1 – Y	1	1.50E-06	4	0.17	34.03	2	-0.012	3	2.0340	3	-60
Lot-1 – Y	1	2.20E-06	5	0.52	20.80	2	-0.007	2	-0.6545	1	19.9
Lot-1 – Z	5	1.26E-05	3	0.20	11.59	2	-0.008	2	0.3850	1	19.4
Lot-1 – Z	5	20.9E-05	5	1.22	20.80	1	0.007	1	0.6387	3	-16

Source: Landlord's Test Result

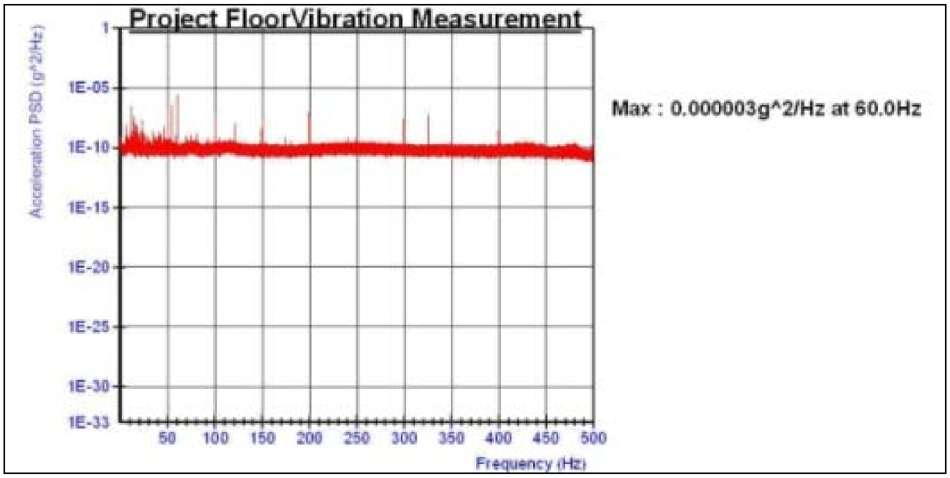
From the above measurement, the vibration profile of building "C" over a 24-hour period is charted. With these information on the vibration profile, company "R" can have its Engineers and consultant analysis the data and make recommendation for suitable measures and controls to be taken to ensure that there is no undue influence from surrounding factors that may affect the interest of the company.



Typical Floor Vibration Data – X Direction Read-Out



Typical Floor Vibration Data – Y Direction Read-Out



Typical Floor Vibration Data – Z Direction Read-Out

Conclusion of Floor Vibration Measurement

As evident by the floor vibration measurement conducted by a 3rd party consultant, building "C" was found to be a "silent and vibration-free" building. The results obtained from the 24-hours period shows that the building was within the acceptable limit of the client, in regards to vibration concern.

The building vibration profile showed that there is no undue influence from its existing tenants and landlords' activities and the expressway is not contributing to any adverse vibration. With this profile, the client is being able to assess the vibration controls needed for its machine.

However, company "R" must note that the vibration profile taken will only be applicable at this point of time as the vibration profiles will necessary change in time as more tenant moves in to building "C". Thus, company "R" has to take into account of future vibration contributions that may arise from external factors, i.e. new tenants with a set of vibration profile added on to the building.

Recommendation for Good Practices

Introduction

In many industrial plants, there may be several noise, and thus vibration, sources that may contribute to the noise and vibration level.

Good practices can help in ensuring quality of end products, more importantly; it can help in protecting employees from the harmful effects that comes along with prolong exposure to noise and vibrations.

If the suspected source which is contributing these noise and vibration can be operated independently of other machinery, switching it off may be one of the mist reliable methods of source identification.

Identification of Source

Source identification may be preformed by the following way;

- Location of source of impact
    - Listen to the machine and identify the parts or components which are generating the noise. Running the machine at a reduced speed or running automatic machine under manual control may help in identifying the source.

- Isolation of suspected source
    - Isolation of the suspected parts of the machine to identify the source.

- Sources with unusual time variations
    - Look for source of noise and vibration which undergoes change while condition elsewhere remains the same.

- Location of radiating surfaces
    - The loudest sound radiation is usually near the point of the highest sound level around the machine.

- Characteristic sources within a machine
    - Removal of the exterior of the suspected source to reveal the source within the machine by looking for sources with noticeable characteristic.

- Location of transmission eccentricities
    - Noise which is modulated is often caused by bent shafts or eccentrically mounted gear or pulleys. By changing the speed of the inspected machine, the source may be identified.

- Location of worn bearings
    - Noise level increases as the rotational speed of the shaft increases.

- Location of sources of tone
    - By changing the running speed of the machine and noting if the changes affect the level and frequency of the tone.

- Test of tool or saw-blade errors
    - Quality of the machine surface or cutter affecting the noise and vibration level.

- Location of loose panels or components
    - Identifying loose panels or components.

- Test for fan noise
    - Test for fan efficiency and inspect fan blades.

- Test for flow-generated noise
    - Removal of sharp edges and constriction from the flow.

- Effect of load on system
    - Comparing the noise and vibration level of machines at idle with that when under load.

Methods of Noise and Vibration Controls

The control of noise and vibration can be achieved by 3 approaches:

1. Engineering Methods

2. Administrative Measures

3. Personal Protection

Engineering Methods

Engineering methods to control noise and vibration levels are essentially physical means to reduce the noise and vibration at either the source, along the path and vicinity of the zone.

Engineering controls are often permanent and effective means of solving and preventing the problems. Therefore, it is often used as a primary means of control where it is practicable.

These controls include substitution of machinery parts, processes, the installation of barriers or enclosures and the modification of the sources.

Administrative Measures

By limiting the exposure of employees to the source within the acceptable limits of the law. These measures include careful planning and production scheduling to fit the cycles of production.

Administrative measures should only be considered when engineering methods cannot be used to control the noise and vibration levels to an acceptable limits. This includes the surrounding factors whereby peaceful ambient is enjoyed by any neighbours.

Personal Protection

Where engineering and administrative measure are used to control and limit exposure to noise and vibration, personal protection is imperative in ensuring employees are provided with appropriate protection.

The use of engineering controls and any administrative measures may reduce the effect of exposure, however, with personal protection equipment, an additional level of preventive measure is provided.

Planning

Noise and vibration problem can be avoided, or minimized, by proper design and proper detailing of the each structural component of a building / factory. Structural Engineers, who has prior knowledge of the use of the building, in the design stage, can overcome the expected noise and vibration requirement that the floor space is to be exposed to. However, this can only be done for new building that is to be constructed. In the context of existing buildings, it is often to find a building that will cater for the requirement as requested by the occupiers of the space. Likewise for new plant setup, occupiers will often not find a floor space that will cater to their needs. Thus, the alternative to overcome the problems of noise and vibration will be to avoid or minimized by proper plant design and the careful selection of equipment. It is often less expensive to design a quiet factory than to implement noise and vibration control after the plant is in operation.

Plants layout should be planned such that machines are not group together or located near sound reflective walls or in corners. Generally, equipment should be housed in rooms built of heavy, tight construction as far away from occupied or critical area as it may be possible. Machines with low frequency vibration should be mounted on vibration isolators or on separate foundations.

General considerations in plant planning are as follows:

1. Where purchasing of new machineries, specify and select quiet-running machinery where possible.

2. Noisy machines and machines that produce vibration should not be placed in the centre of a quiet or populated area.

3. Avoid locating machines near reflective walls and corner of space.

4. Plan layout of machines such that only minimum number of staffs are affected.

5. In populated area where the machine is to be located, allow for sufficient area for an enclosure or a separate room to house the machines.

6. Where multiple machines are located near each other, minimize exposure of operator and machines with barrier between each machines.

7. Where machines operate continuously, isolate the machine in a separate room.

Controls of Noise and Vibration by Engineering Methods

To determine the appropriate noise and vibration controls to be applied onto each machine, the control treatment for machines can be determined by following the procedures:

A. Measure the sound pressure level and vibration level, where possible, to determine if the machine is within the acceptable specification as required by the operation.

B. Check with the require specification of the machine and ensure levels are met.

C. Calculate the reduction levels, if any.

D. Select the control device or material for improvement.

Basing on the reduction calculated, an appropriate noise and vibration control treatment could be selected or applied to limit the generation, transmission or radiation of noise and vibration caused by the various paths and sources that has be identified.

Noise and vibration may be reduced by proper substitution of equipment or implementation of alternative process. Equipment or processes are inherently different from each other. It is often more economical to choose a quieter, more expensive machine or process than to use a cheaper type which will require considerable additional noise and vibration control.

Individual treatments must be selected to fit each machines such that the total effect will meet the design goal level that the company intends to achieve. These improvement should be work in such way that the lowest cost possible is given to the owners without due interference with the operation, maintenance and safety of the equipment and employees.

Engineering Noise Controls

The basic classes of materials used for engineering noise control, particularly for construction of acoustical enclosure and barriers are:

A. Sound attenuating materials, which reduce sound transmission between adjacent spaces.
B. Sound absorption materials, which absorb sound from surfaces and reduce reverberation.

The choice of materials for achieving acoustic performance is dependent on various factors:

- Availability of space for treatment.
- Conditions of access for application of treatment.
- Effects of moisture, condensation and heat.
- Requirements and methods of maintenance.
- Likelihood of and protection from impact or damage.
- Requirement for fire control.
- Possible combination of acoustic treatment with thermal insulation.
- Compatibility of treatment with the process and any possible interaction with the process.

The control of noise can be in other methods of application such as:

- Noise Barriers
- Partition Walls
- Machine Enclosure
- Personnel Enclosure
- Room Absorption

- Damping of equipments

Engineering Vibration Controls

Vibration control measures may be implemented by:

- Reducing the mechanical disturbance causing the vibration,
- Isolating the disturbance from the radiating surface, and
- Reducing the response of the radiating surface.

A) Mounting of Equipment

Structural borne disturbance may be often reduced by mounting and/or isolating the machine to minimize transmission of vibration from the machine to the load bearing structure of the building.

In practical, there are 3 ways of mounting equipment;

1. Attach vibration isolators direct to the existing mounting feet of the equipment.

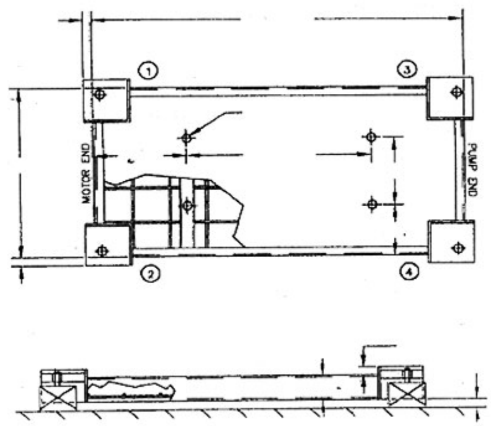
   Applicable to small and compact equipment. Suitable when equipment is rigid and is not liable to distortion when supported by its existing feet.

2. Mounting the equipment on a steel frame base an attach the vibration isolators to this base.

   Applicable when there is more than one unit of equipment or if it is of significant size. Steel sub-frame is made sufficiently strong to provide for the necessary support.

3. Mounting the equipment on a built-to-order concrete inertia base.

   Applicable for strong vibrating machines which require separate foundations or concrete inertia blocks to prevent the propagation of structural borne vibration and noise. Concrete inertia block lowers the centre of gravity, thereby increasing the stability to the mechanical system and the effectiveness of the vibration system. Concrete inertia blocks, which are usually made of concrete, poured in structural steel frame with reinforcement bars, acts to reduce the movement of the mounted equipment.



Concrete Inertia Base

B) Vibration Isolators

The function of a vibration isolator is to minimize the transmission of shaking forces from a machine to its supporting structural, thus, these isolators, when installed properly, will effectively reduce, if not isolate vibration.

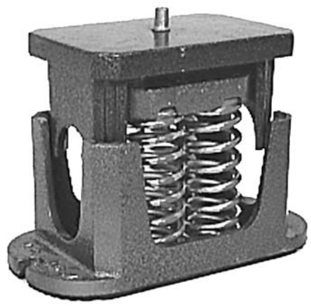
Vibration isolators can be in the form of steel springs, rubber, felt, cork, dense fiberglass, neoprene and other elastomers. Vibration isolators are selected by specifying the weight supported, the deflection required and the lowest vibratory frequency of the unit to be isolated.

Springs

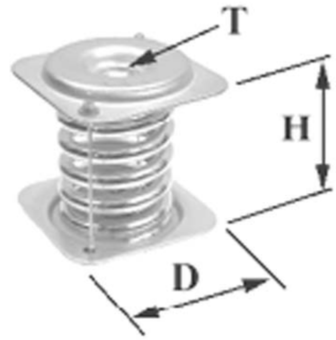
Steel coil springs are most commonly used as they are highly efficient mechanical vibration absorbers, durable and available with a wide range of flexibility. Coiled springs are capable of providing natural frequencies down to about 8 Hz.

Steel springs are virtually undamped. They have a disadvantage that high frequencies vibration can travel along the wire of the coil to transmit vibration into the structure. As such, to overcome this, a spring may be installed with a elastomer pad combined in the spring assembly so that there is no metal-to-metal contact.

Spring isolators are usually either housed or free standing. They are excellent isolators for both steady state vibration and for impact machines. Free standing springs are unconstrained devices which must be stabilized. Housed spring may vary in design and can be furnished with either vertical or lateral restraints depending on the need. Housed springs are usually preferred over free standing springs for in-plant installation.



Housed Spring Isolators Mount



Free-Standing Spring Isolators Mount

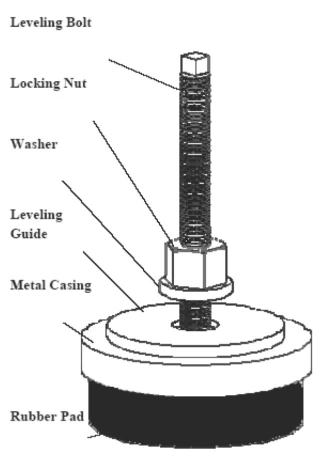
Elastomers

Natural rubber and neoprene isolators are probably the most versatile of all isolators which can be used either in compression or shear.

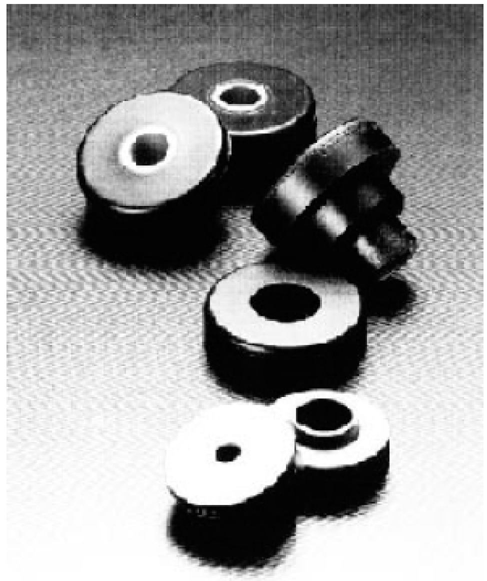
Isolators of this type can be moulded in a variety of shapes and size, to the desired stiffness characteristic of the requirement in both vertical and lateral directions. They can be used for static deflection of up to 12mm and are capable of providing natural frequencies down to about 5 Hz.

Elastomers are cheap and have the advantage that their performance is maintained at high frequencies and that they normally possess sufficient internal damping that permits them to operate at the machine resonance frequency for short periods of time.

Its disadvantage is that they may creep excessively over time. Thus, for this reason, they should not be subjected to continuous strains exceeding 10% compression or 25% shear.



Foot Mounts with Elastomer Pad



Typical Elastomers Mounts

Ribbed Elastomers

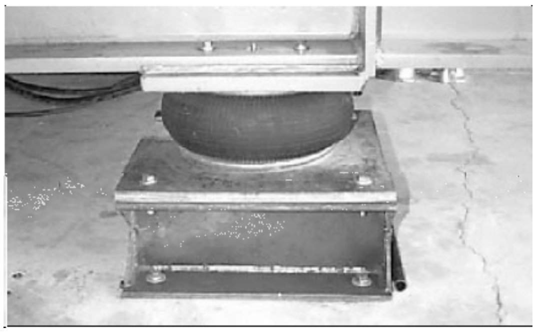
These are used where static deflection of 6mm or less is desired. Ribbed elastomers can be in the form of ribbed rubber, rubber-and-cork sandwich pads or other similar pads.

Ribbed Elastomers are not safe to provide for natural frequencies of below 10 Hz. They are inexpensive forms of resilient pads for machines of high speed with negligible imbalance.

Ribbed Elastomer Pads

Pneumatic Isolators

Pneumatic isolators, air springs, or air mounts are particularly useful when low driving frequencies are present. These isolators offered efficiencies of up to 90% at low natural frequencies from below 10 Hz without the large static deflection required of steel springs. These isolators are excellent lateral stabilities with adequate internal damping and self leveling by means of air volume control and shock protection. However, their disadvantage is that, compared to steel spring, they are more expensive and is limited by the load capacity with the necessity of periodic maintenance.



Air Mount Assembly

Other Materials

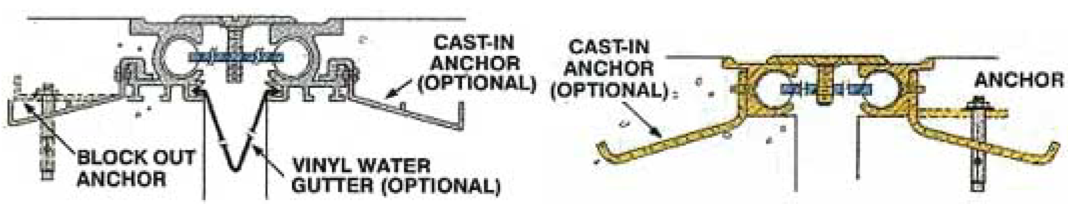
Other material used as vibration isolators are wool felt, cork, glass fibers, foam, wire mesh etc. These isolators are often used in pad or blanket form, as their vibration absorbing properties are not well documented as in those mentioned above, the selection criteria for them are questionable.

Other Effective Commercial Engineering Controls for Vibration

Installation of Vibration Controls at Expansion Joints

Expansion joints are essential for long-lasting trouble free stable floor base. By installing vibration controls at expansion joints, selected areas are protected from vibration transmitted by the machines housed inside the zones of the expansion joints. The expansion joints are designed to permit multi-directional six way movement. This allows for movement between sections of concrete flooring, without damaging the surrounding concrete and paving. The expansion joints controls can be fabricated and installed to any width or joint movement to fit all requirement.

Expansion Joint



Cross sectional view of two types of Expansion Joints

<u>Mitigation of Vibration using Passive and Active Dampers</u>

In tall slender structures, deformation and motion perception due to wind-induced vibration have become more prevalent and could lead to failure of the serviceability limit of the building. Thus, in order to meet the serviceability requirements, a significant number of tall buildings and towers are fitted with a variety of passive and active vibration control devices.

Among these devices are the tuned mass dampers (TMD), tuned liquid dampers (TLD) and tuned liquid column dampers (TLCD).

The TLD consists of a container which is partially filled with liquid. When it is mounted on a building subjected to vibration, it dissipates energy through the sloshing action of liquid in the container (Figure 1). For optimum results, the sloshing frequency is tuned to the frequency of the structure. Since the wind load is random, a theoretical model to predict the motion of shallow liquid in a rectangular tank has been developed for non-periodic excitation. The model accounts for energy dissipation arising from liquid viscosity. A numerical procedure has been formulated for the dynamic analysis of TLD-structure interaction. In order to verify the theoretical model, an experimental study was conducted using a shake table. The theoretical model was verified by good agreement between numerical and experimental results. For further improvement in efficiency of operation, the concept of multiple-mode TLDs has been proposed. The optimal locations and optimal mass proportions of TLDs in a structure, modelled as a multi-degree of freedom system, have also been found.

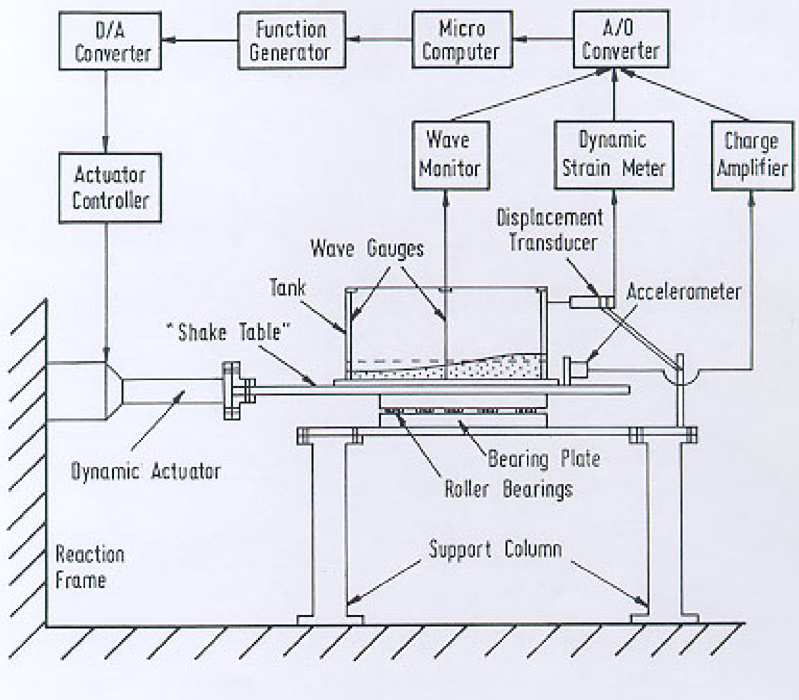


Figure 1 Shake table test on rectangular liquid damper

The TLCD consists of a column of liquid in a U-tube fitted with orifices. When it is mounted on a building subjected to wind-induced vibration, part of the wind energy is absorbed in the form of kinetic energy in the oscillating liquid column, and dissipated in the orifices. The period of oscillation of the liquid column is tuned to the structural period for optimum performance. A parametric study carried out on TLCD revealed that it is a good alternative to the more commonly-used tuned mass damper (TMD) – a device consisting of a mass attached to the building via a spring and dashpot system, where energy is dissipated by the dashpot when the TMD oscillates at the same frequency as the structure but with a phase shift.

In order to improve the performance of the TLCD, an active tuned liquid column damper system (ATLCD) shown in Figure 2 is proposed, where the TLCD is placed on a movable platform mounted in the building. The movement of the platform is controlled by a spring and dashpot when it is driven by a control force. A servo-actuator is used to generate the force based on feedback from the sensor attached to the structure. Accordingly, the acceleration of the structure has been found to be greatly reduced by the use of the ATLCD system vis-a-vis the TLCD system.

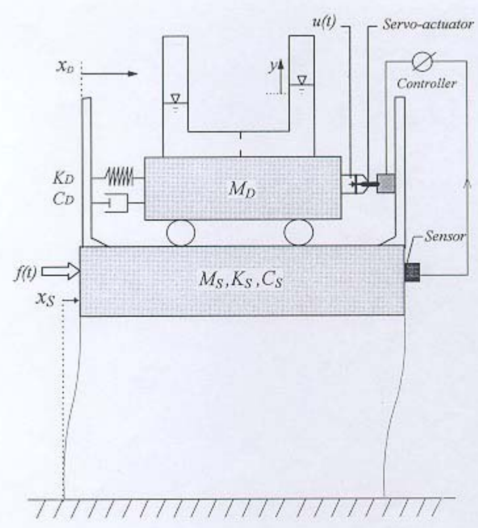


Figure 2 Active tuned liquid column dampers (ATLCD)

Since the liquid in the tube of TLCD has the freedom to oscillate in sympathy to the motion of the structure, while the motion of the tube is actively controlled, the proposed system may be viewed as a hybrid system similar to the composite active-passive tuned mass damper (APTMD) system which has been installed recently in the 145m tall DOWA Phoenix Tower in Osaka, Japan. In the APTMD, an active TMD is attached to a passive TMD, as shown in Figure 3. It is evident that the control effect of ATLCD is better than that of APTMD. Moreover, considering the advantages of TLCD over TMD, the proposed ATLCD system has the potential to be the preferred vibration control system for wind-resistant structures.

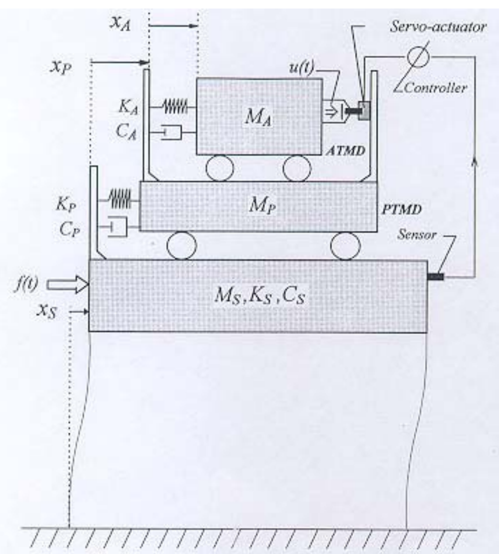


Figure 3 Active-passive tuned mass dampers (APTMD)

Application of the tuned mass dampers (TMD), tuned liquid dampers (TLD) and tuned liquid column dampers (TLCD) are more suitable for application to building on the on-set of construction. This is due to the fact that these systems require proper designing of the foundations to incorporate.

At the present, these systems are used mostly in earthquake borne countries for the propose of damping the effects of earthquakes, however, with proper application, these system may be applicable to building that require vibration controls beyond the tolerance limit of vibration as provided by methods of the normal building construction.

REFERENCES

Ministry of Manpower, Guideline for Noise and Vibration Controls

Ministry of Manpower, Factories Act

Ministry of Manpower, Occupational Safety and Health Guidelines